Fundamentals of pacemakers

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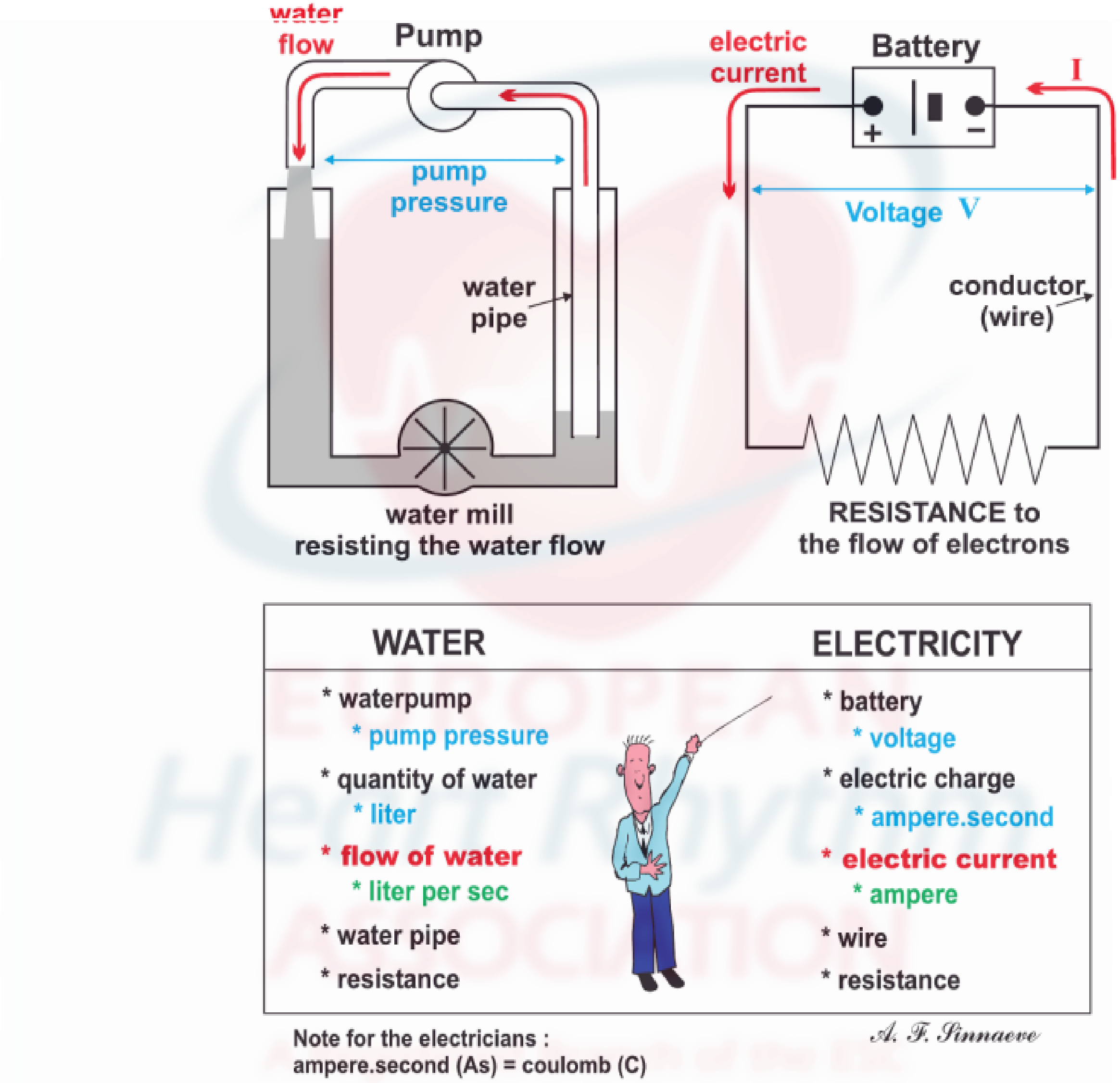
Basic electrical concepts



WATER	ELECTRICITY
* waterpump	* battery
* pump pressure	* voltage
* quantity of water	* electric charge
* liter	* ampere.second
* flow of water	* electric current
* liter per sec	* ampere
* water pipe	* wire
* resistance	* resistance

Note for the electricians :
ampere.second (As) = coulomb (C)

A. F. Sinnaeve

From: Cardiac pacemakers, step by step by Barold, Stroobandt, Sinnaeve. Blackwell Publishing, 2004

Fundamental laws

Ohm's law:

$$I\ (\text{amps}) = \frac{V\ (\text{volts})}{R\ (\Omega)}$$

$$\text{Energy}\ (\text{joules}) = V\ (\text{volts}) \times I\ (\text{amps}) \times \text{time}\ (\text{seconds})$$

. . . . . Combine the two equations

$$E(\text{joules}) = V(\text{volts}) \times \frac{V(\text{volts})}{R(\Omega)} \times t(\text{seconds})$$

$$E(\text{joules}) = \frac{V^{2}(\text{volts})}{R(\Omega)} \times t(\text{seconds})$$

Programming Effects On Energy

$$\boxed{E = \frac{V^2}{R} \times t}$$

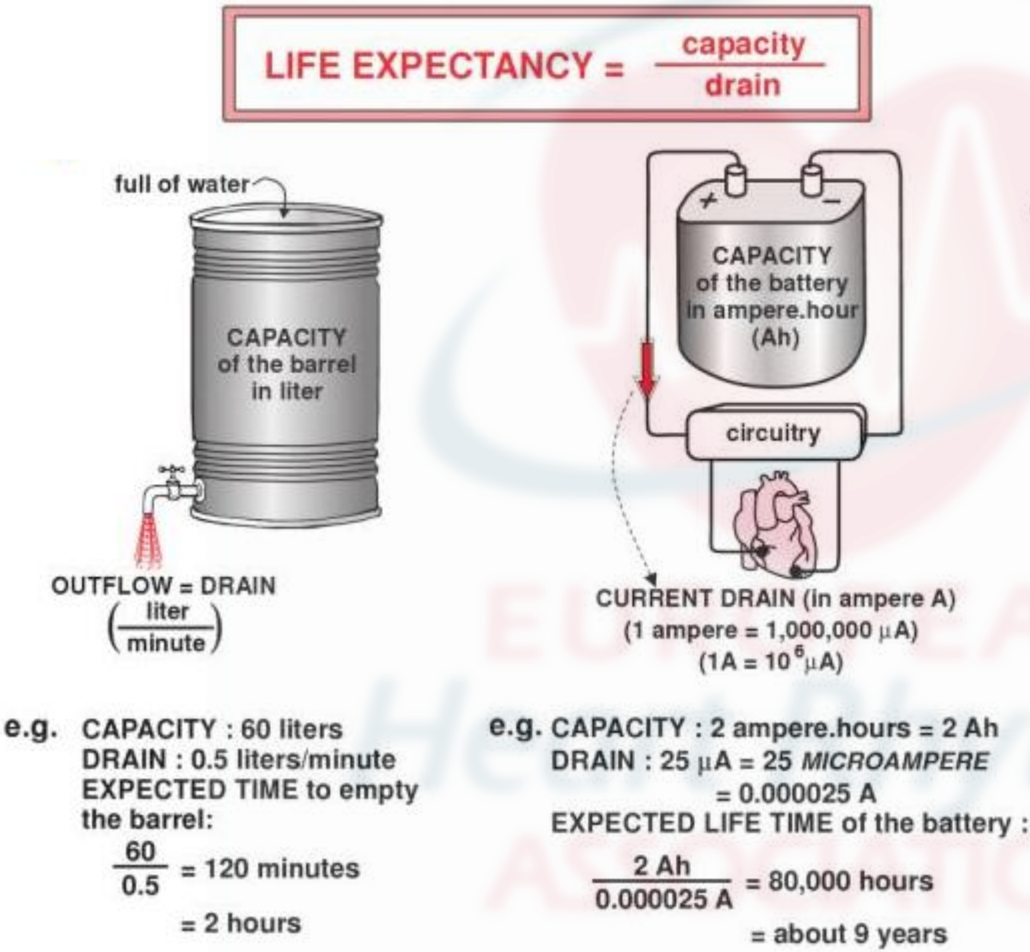
If you take half of the Pulse Width (time) then you use

half of the energy.

If you take half of the Voltage then you use

a quarter !! of the energy.

Battery capacity



LIFE EXPECTANCY $= \dfrac{\text{capacity}}{\text{drain}}$

full of water
CAPACITY of the barrel in liter
OUTFLOW = DRAIN (liter / minute)
+
–
CAPACITY of the battery in ampere.hour (Ah)
circuitry
CURRENT DRAIN (in ampere A)
(1 ampere = 1,000,000 µA)
(1A = 10⁶µA)

e.g. CAPACITY : 60 liters
DRAIN : 0.5 liters/minute
EXPECTED TIME to empty the barrel:

$$\frac{60}{0.5} = 120 \text{ minutes}$$

= 2 hours

e.g. CAPACITY : 2 ampere.hours = 2 Ah
DRAIN : 25 µA = 25 *MICROAMPERE*
= 0.000025 A
EXPECTED LIFE TIME of the battery :

$$\frac{2 \text{ Ah}}{0.000025 \text{ A}} = 80{,}000 \text{ hours}$$

= about 9 years

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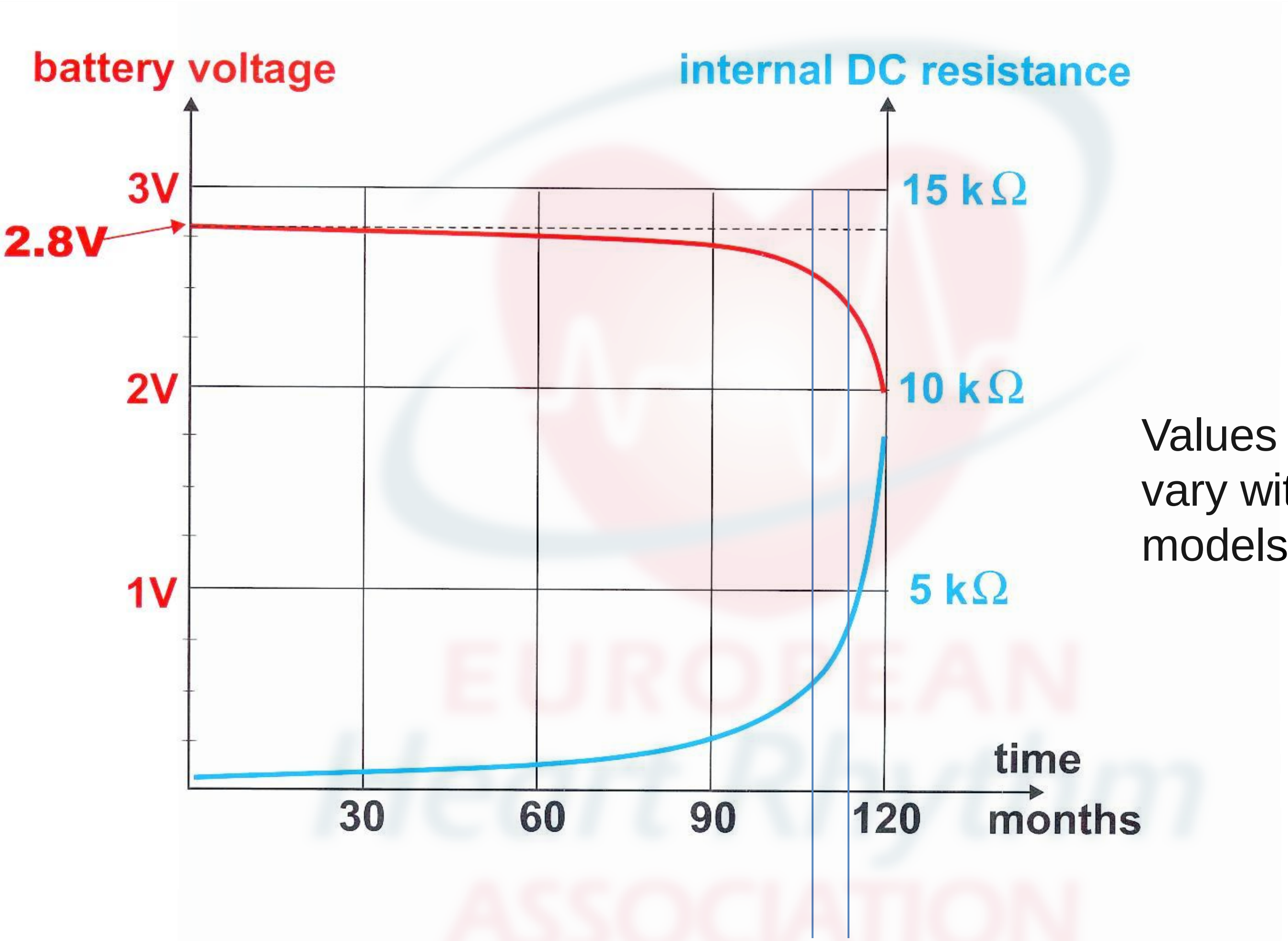
Lithium Battery

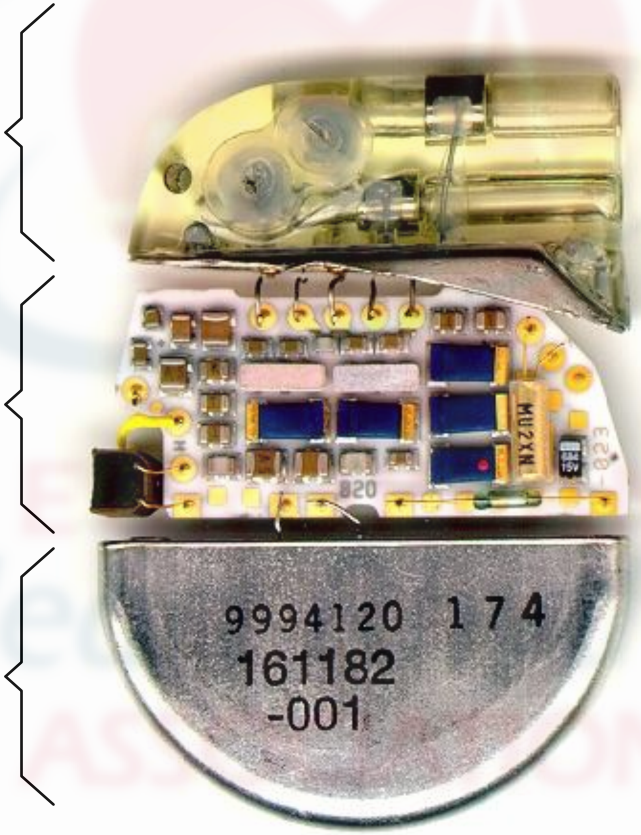


Values of impedances vary with pacemaker models!

ERI
(Elective Replacement Indicator)

EOL
(End of Life)

Anatomy of a pacemaker

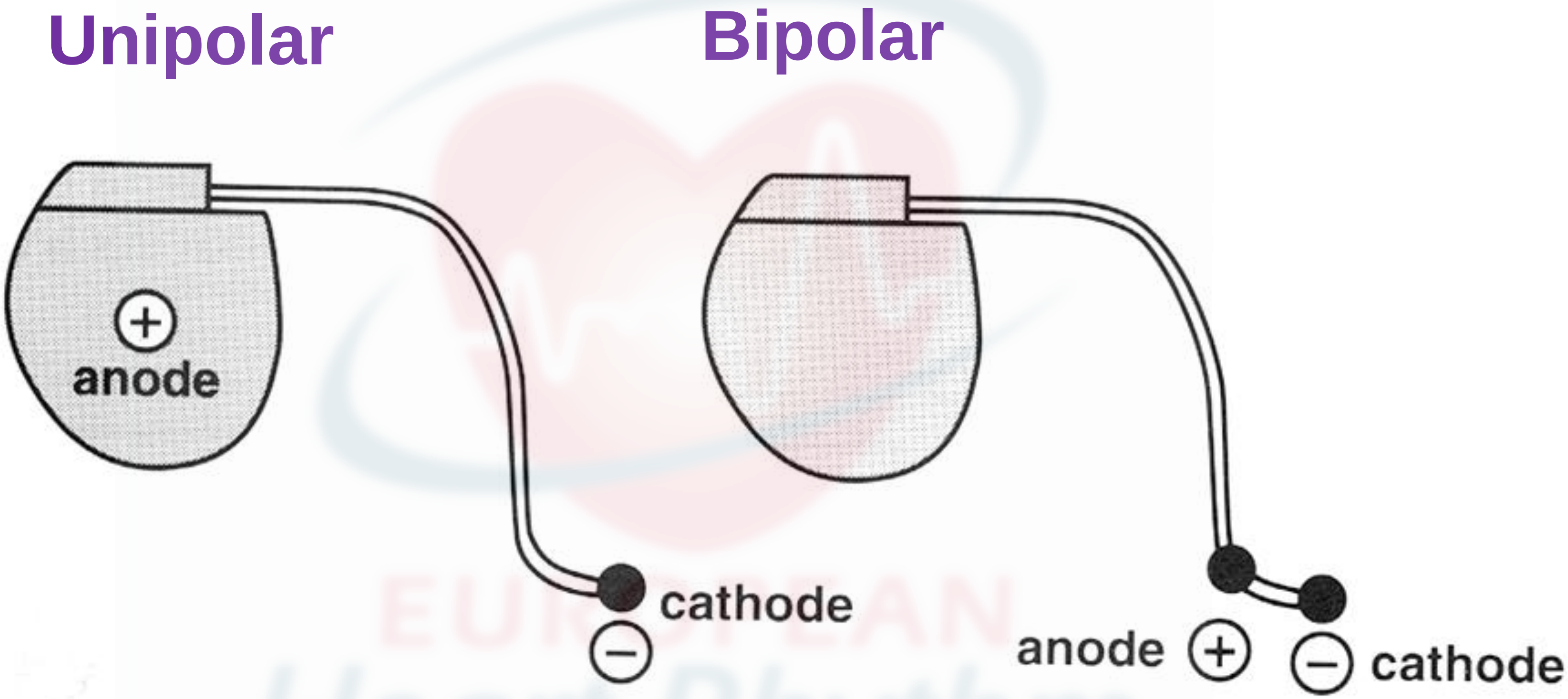


Connector

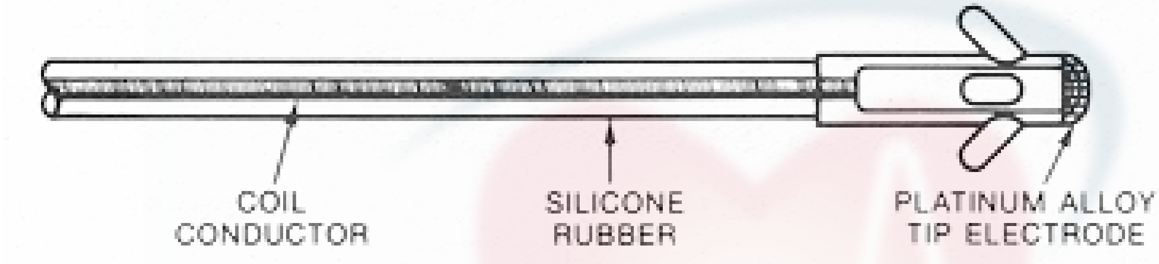
Circuitry

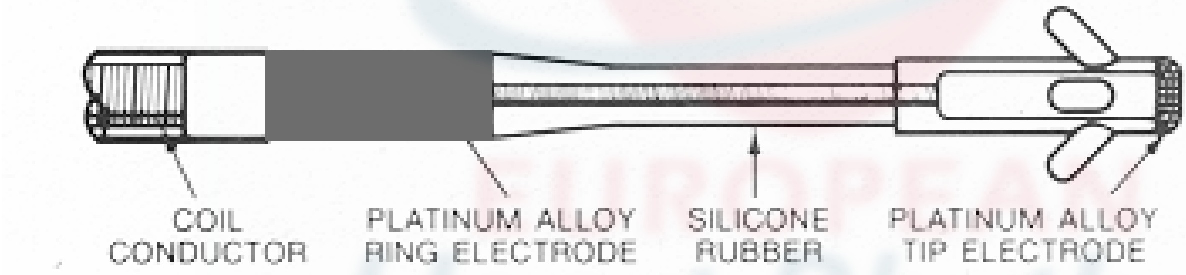
Battery

Unipolar vs. bipolar



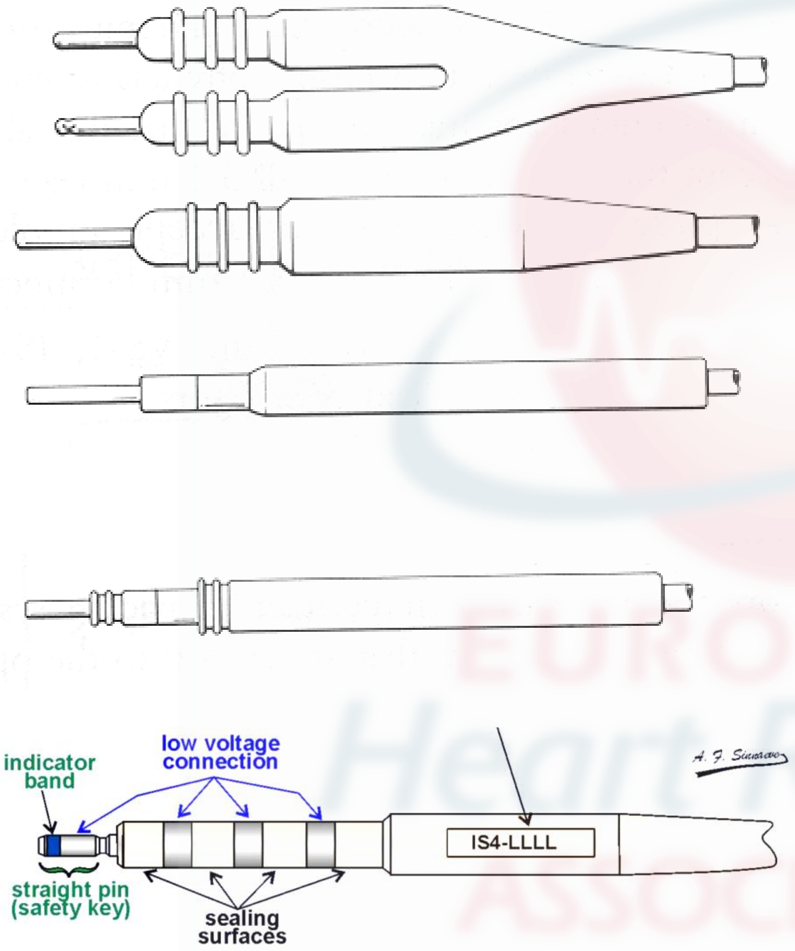
Brady Lead Configuration





Surface of ring anode > tip cathode to avoid anodal capture as well as corrosion

Brady Lead Connector Pins



5 mm bifurcated bipolar

5 mm or 6 mm unipolar

3.2 mm Low Profile

(long pin, no sealing rings)

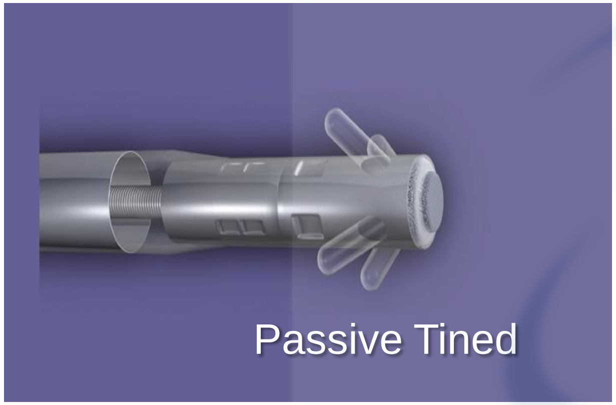
IS-1 / VS-1

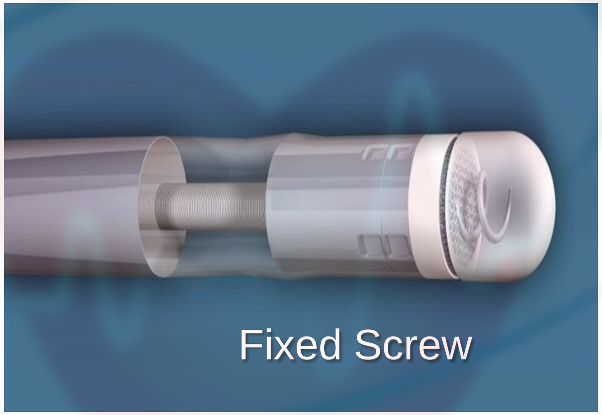
(short pin, with sealing rings)

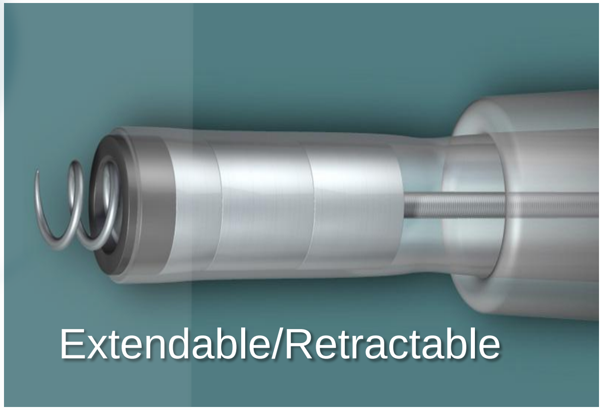
IS-4

(for quadripolar CRT leads)

Lead fixation mechanisms





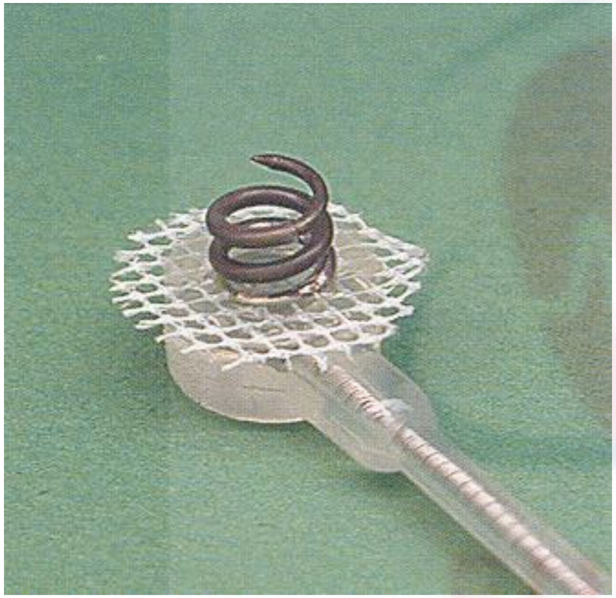


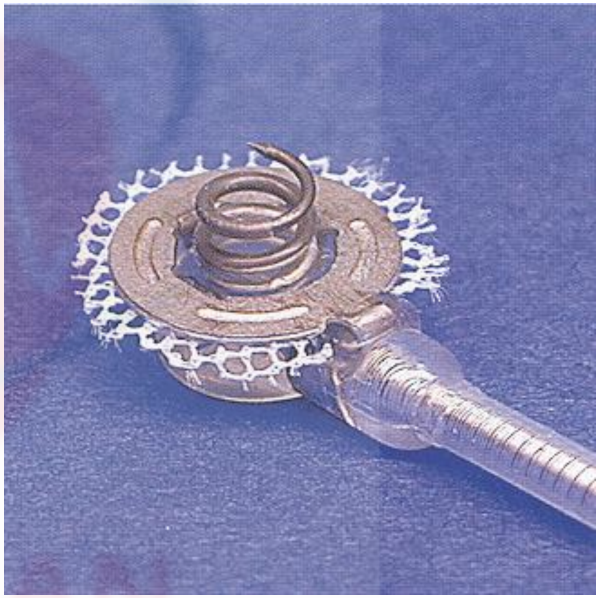
Passive fixation

Active fixed screw

Active screw
Extend./Retract.

Epicardial/Myocardial Leads



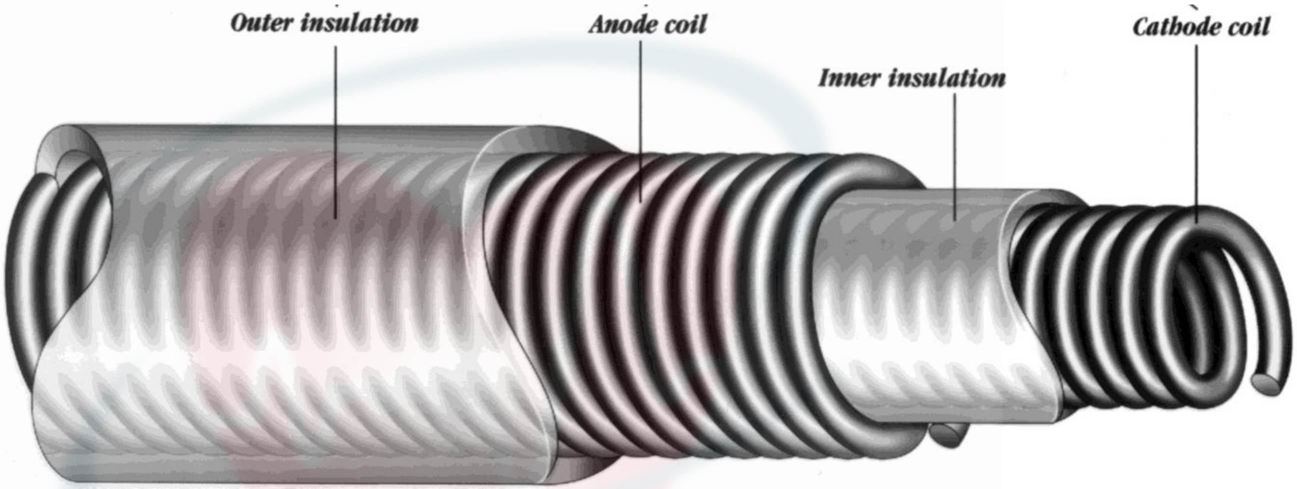


Unipolar

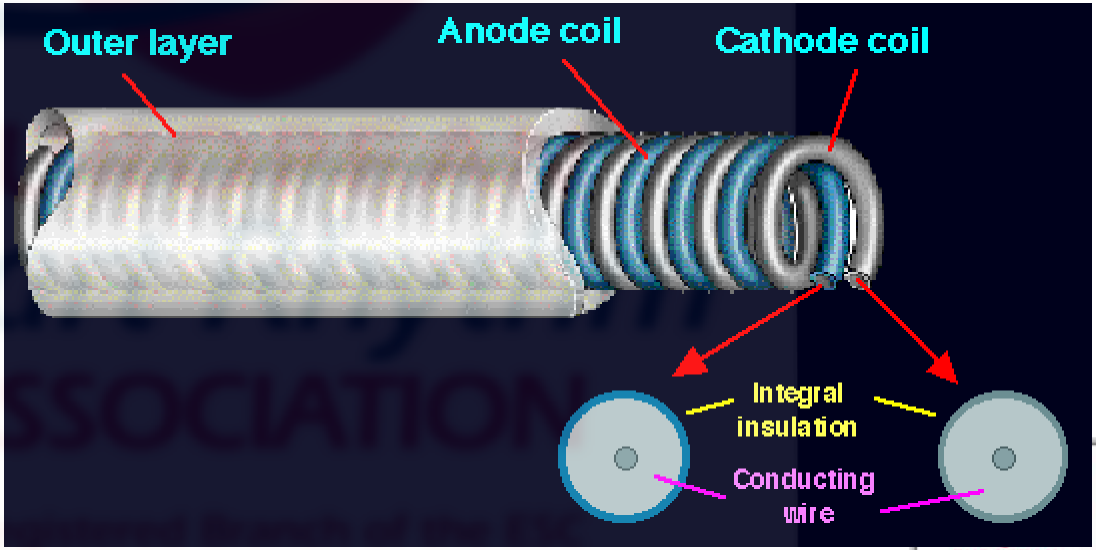
Bipolar

Bipolar Conductor Coils

CoAxial **Design**



CoRadial **Design**

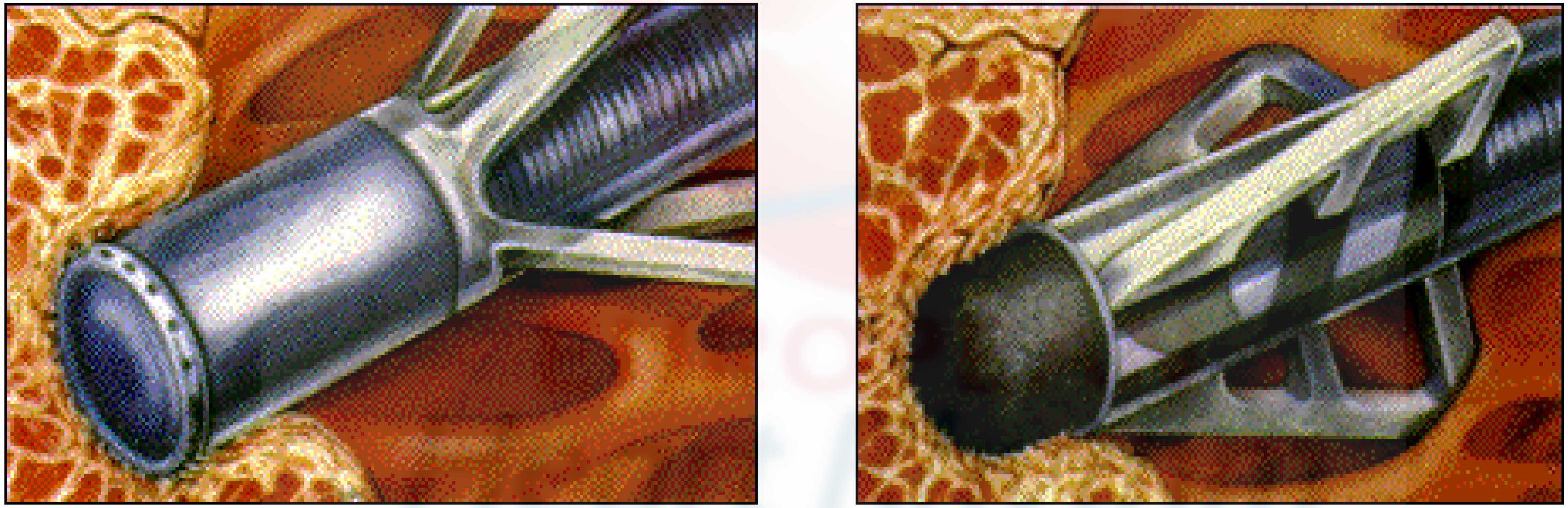


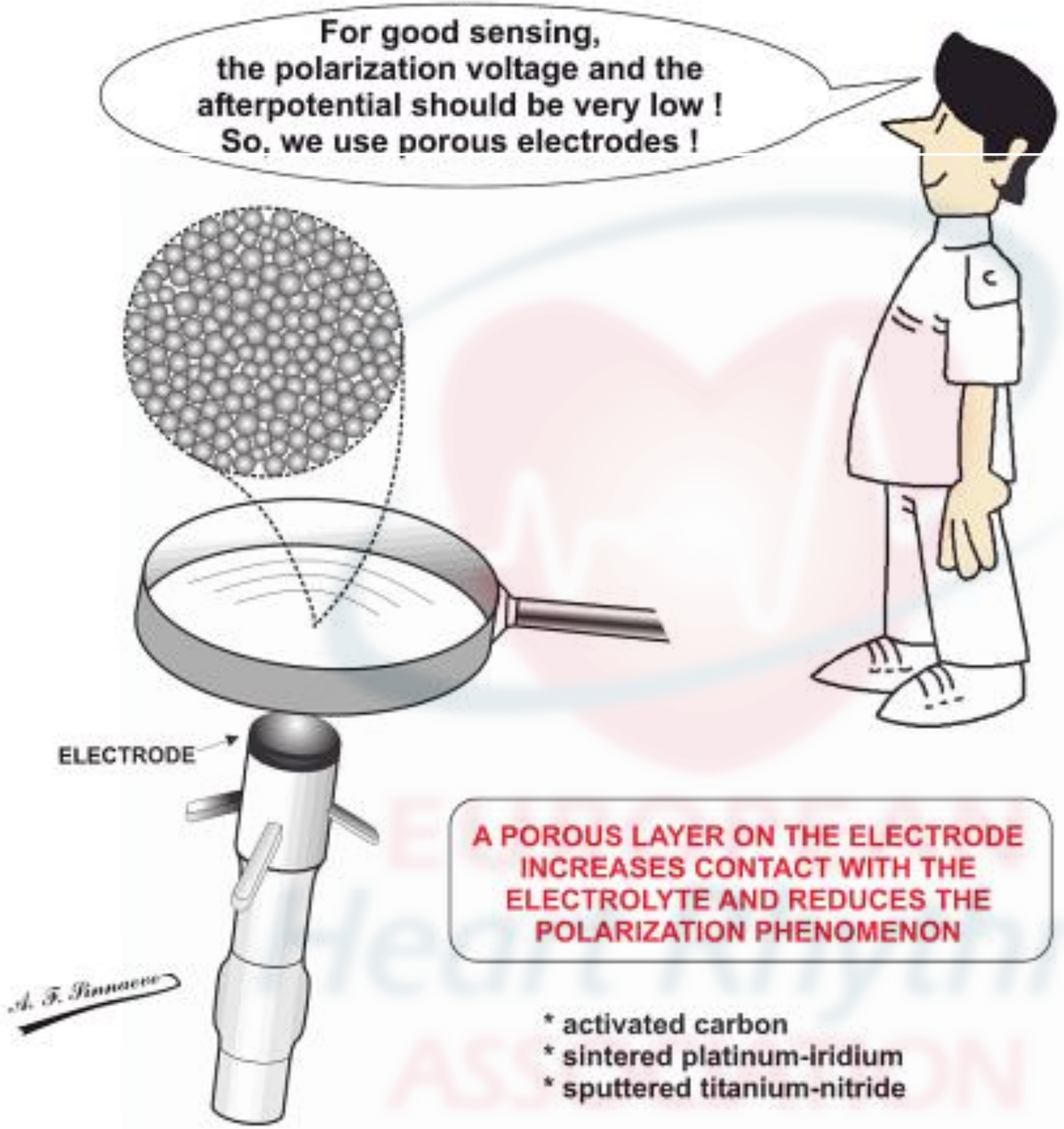
Insulation

	Advantages	Disadvantages
Silicone	Flexible Repairable Proven history	Tears and cuts easily (ligatures) Low abrasion resistance More friction Thrombogenic Thicker leads
Polyurethane	High tear /cut resistance High abrasion resistance Low friction Thinner leads Less thrombogenic	Stiffer Not repairable Stress cracking Metal ion oxidation

Lead Tip Design

Small tip for better pacing (higher current density)
Large porous surface for better sensing

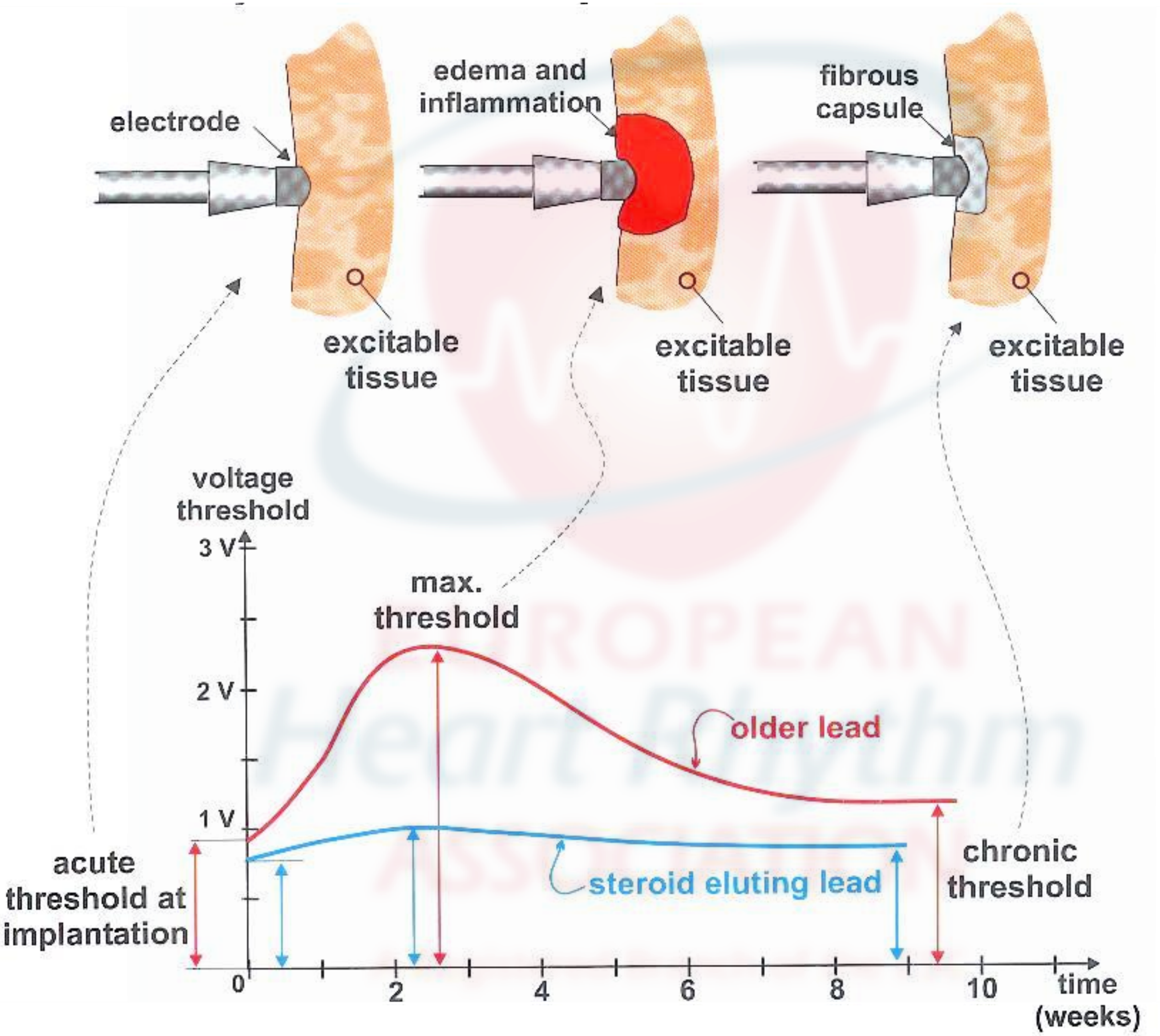



For good sensing,
the polarization voltage and the
afterpotential should be very low !
So, we use porous electrodes !
ELECTRODE
A. F. Pinnacro

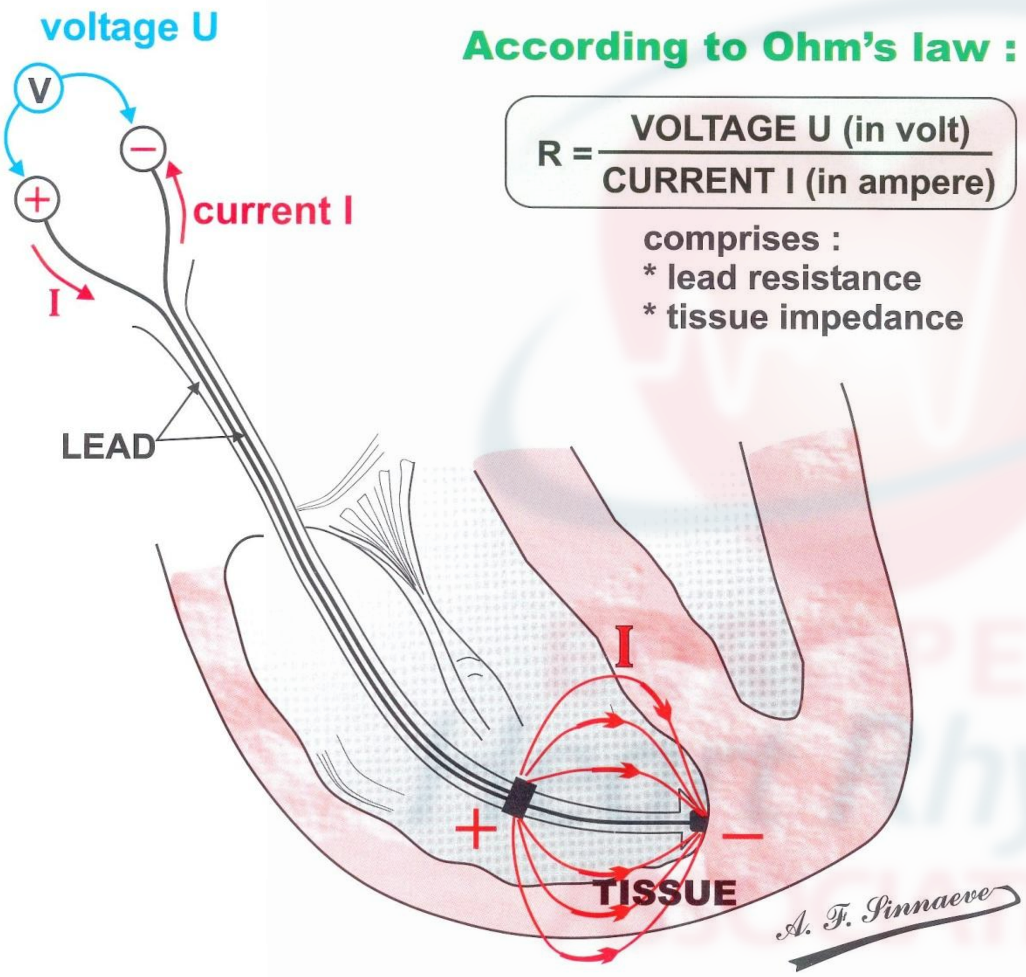
A POROUS LAYER ON THE ELECTRODE INCREASES CONTACT WITH THE ELECTROLYTE AND REDUCES THE POLARIZATION PHENOMENON

* activated carbon
* sintered platinum-iridium
* sputtered titanium-nitride

Steroid-eluting leads



Lead Impedance



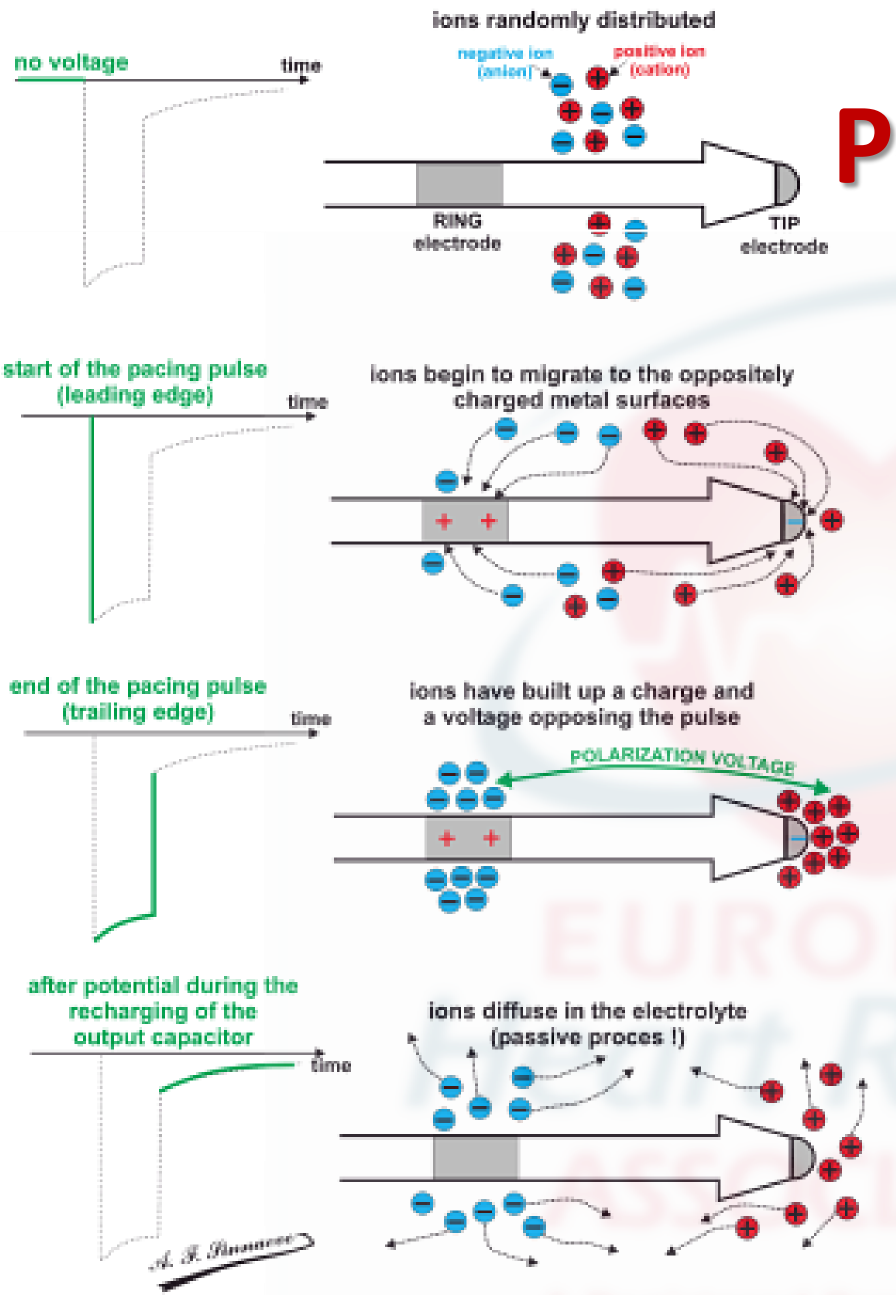
In pacing, resistance is equivalent to impedance and is measured in Ohms (Ω)

Different lead models have different normal ranges of impedances

Higher impedance = less current drain = longer battery longevity

In general if the impedance is:
<200 Ω: insulation defect
>2000 Ω: lead fracture

Polarization


ions randomly distributed
no voltage
time
negative ion (anion)
positive ion (cation)
RING electrode
TIP electrode
start of the pacing pulse (leading edge)
time
ions begin to migrate to the oppositely charged metal surfaces
end of the pacing pulse (trailing edge)
time
ions have built up a charge and a voltage opposing the pulse
POLARIZATION VOLTAGE
after potential during the recharging of the output capacitor
time
ions diffuse in the electrolyte (passive proces !)

The afterpotential

Caused by dissipation of polarization at electrode-tissue interface.

Depends on:

- Pulse amplitude and duration
- Inversely proportional to electrode surface
  - ➔ porous electrode tip

May interfere with sensing

➔ blanking periods >> pulse duration

Modern PMs discharge the afterpotential quickly

From: Cardiac pacemakers, step by step, by Barold, Stroobandt, Sinnaeve. Blackwell Publishing, 2004

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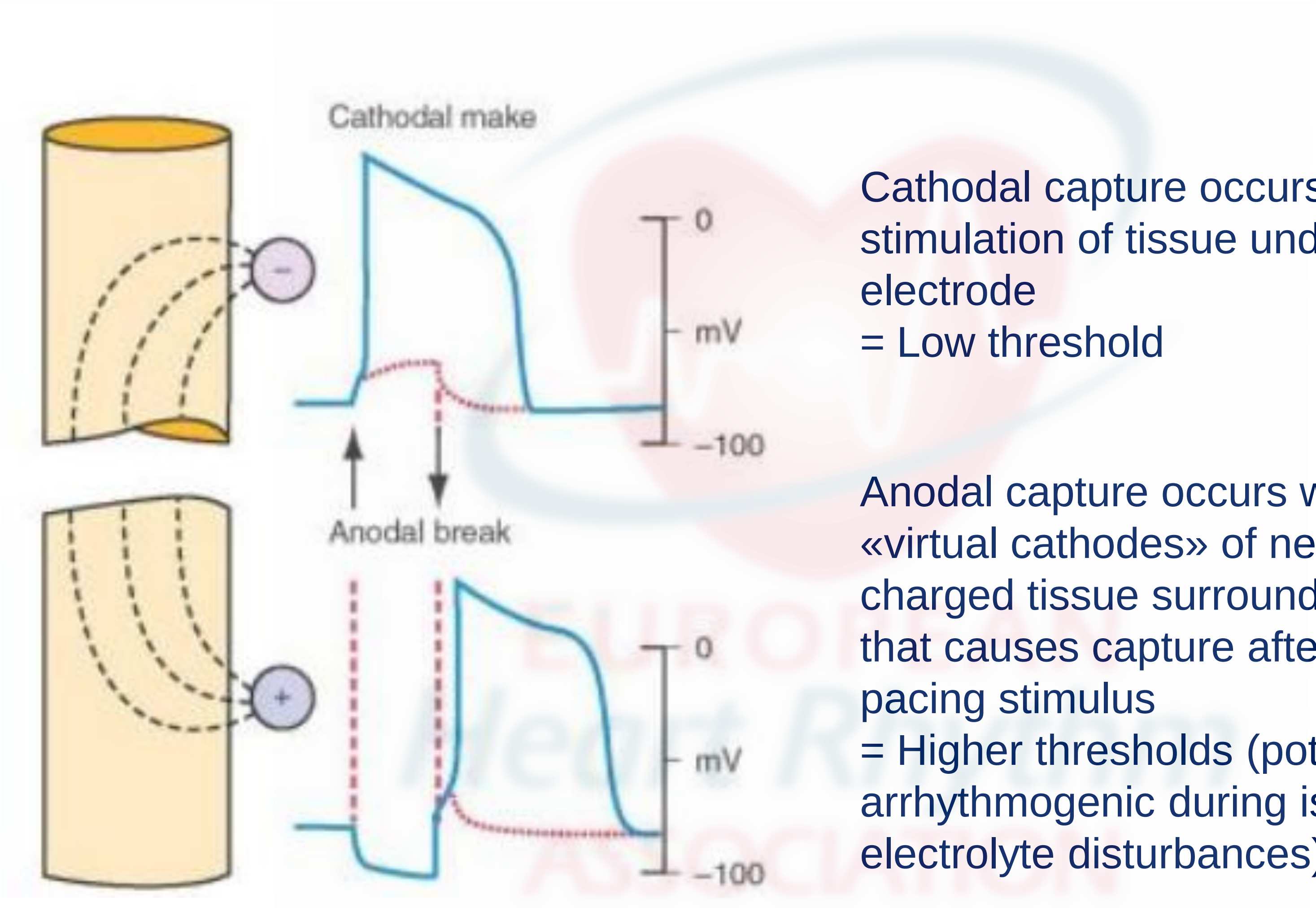
Cathodal and anodal capture

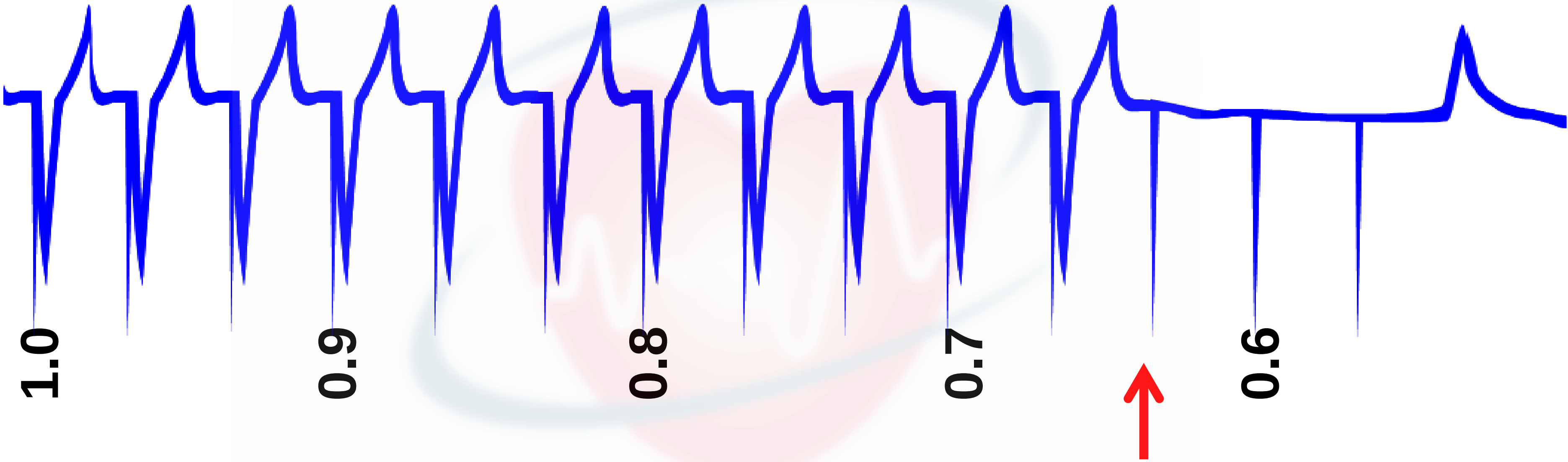


Cathodal capture occurs with direct stimulation of tissue under the electrode
= Low threshold

Anodal capture occurs with creation of «virtual cathodes» of negatively charged tissue surrounding the anode, that causes capture after the end of the pacing stimulus
= Higher thresholds (potentially arrhythmogenic during ischemia and electrolyte disturbances)

From: Ellenbogen, Kay, Lau, Wildoff. Clinical cardiac pacing, defibrillation and resynchronization therapy. Elservier 2011

Threshold Test



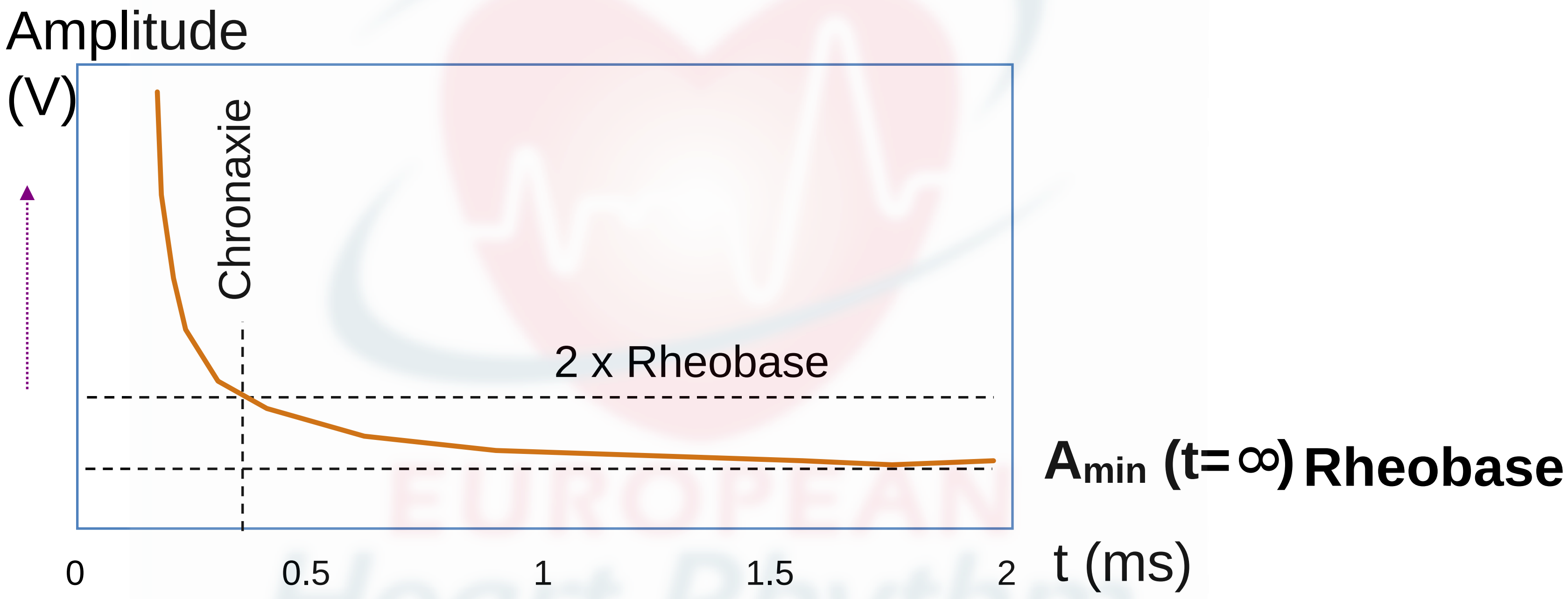
3rd beat at 0.7V with loss of capture

Threshold = value at which *consistent* capture occurs

(=0.8V in this example)

Strength Duration Curve

Relation of the stimulus amplitude to the duration of the pulse width

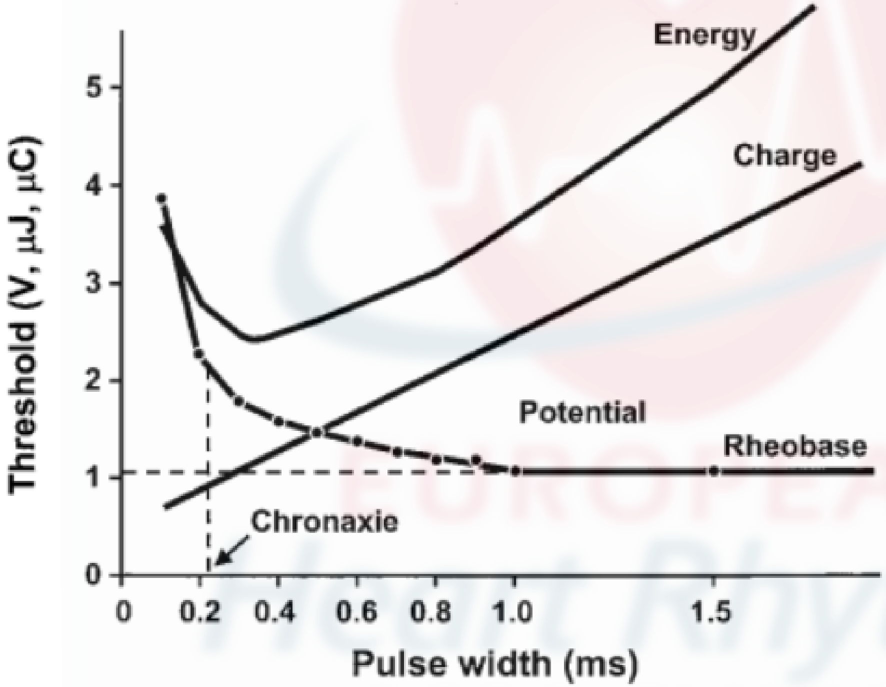


- Rheobase = the minimal amplitude that captures with infinite pulse duration (usually measured for practical purposes at 2ms)
- Chronaxie = the pulse duration at 2 x rheobase amplitude

The optimal pulse width (with minimum threshold energy) = chronaxie duration

100% safety output = 3 x PW threshold

= 2 x Voltage threshold

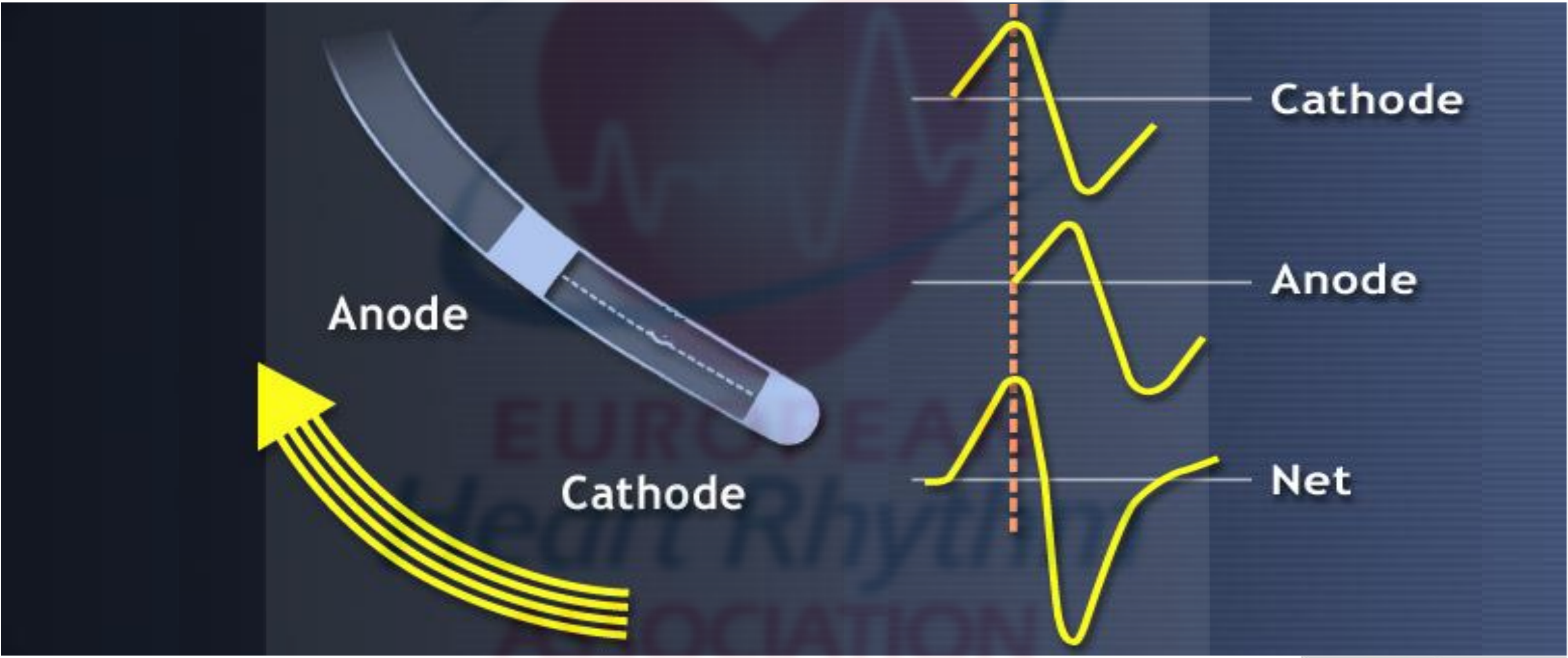


Programming the lowest voltage is most beneficial, since

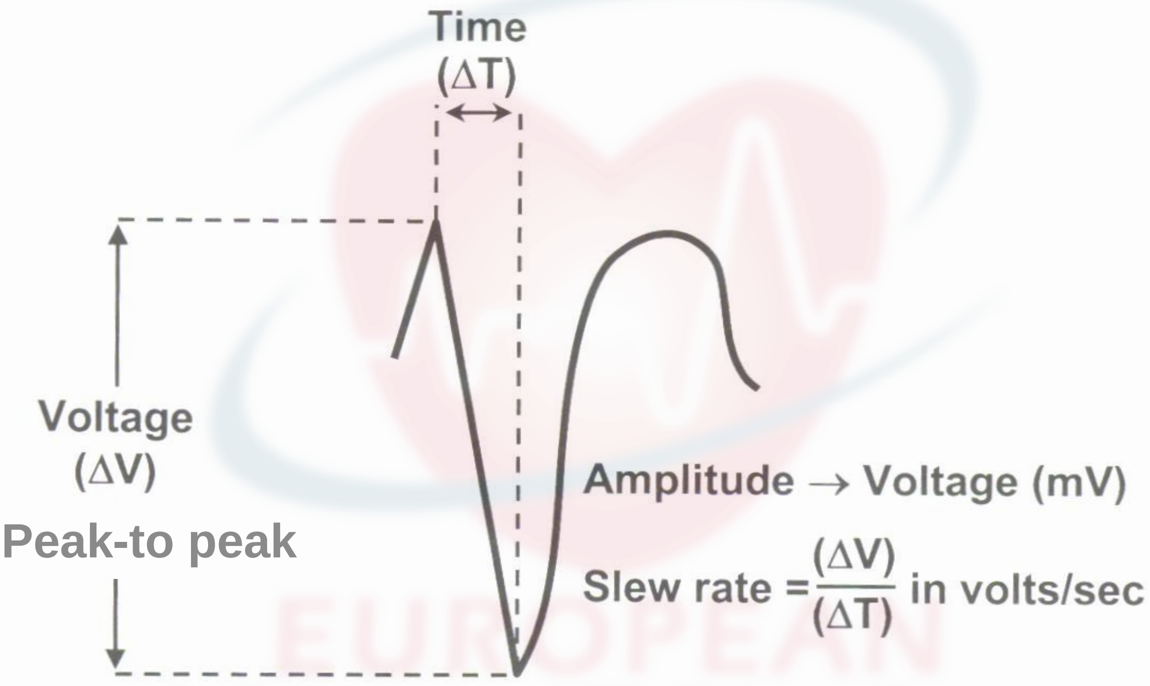
$$\text{Energy} = V^2 . t / R$$

The Intracadiac Electrogram (IEGM)

Intrinsicoid deflection occurs when the depolarization wavefront passes under the electrode



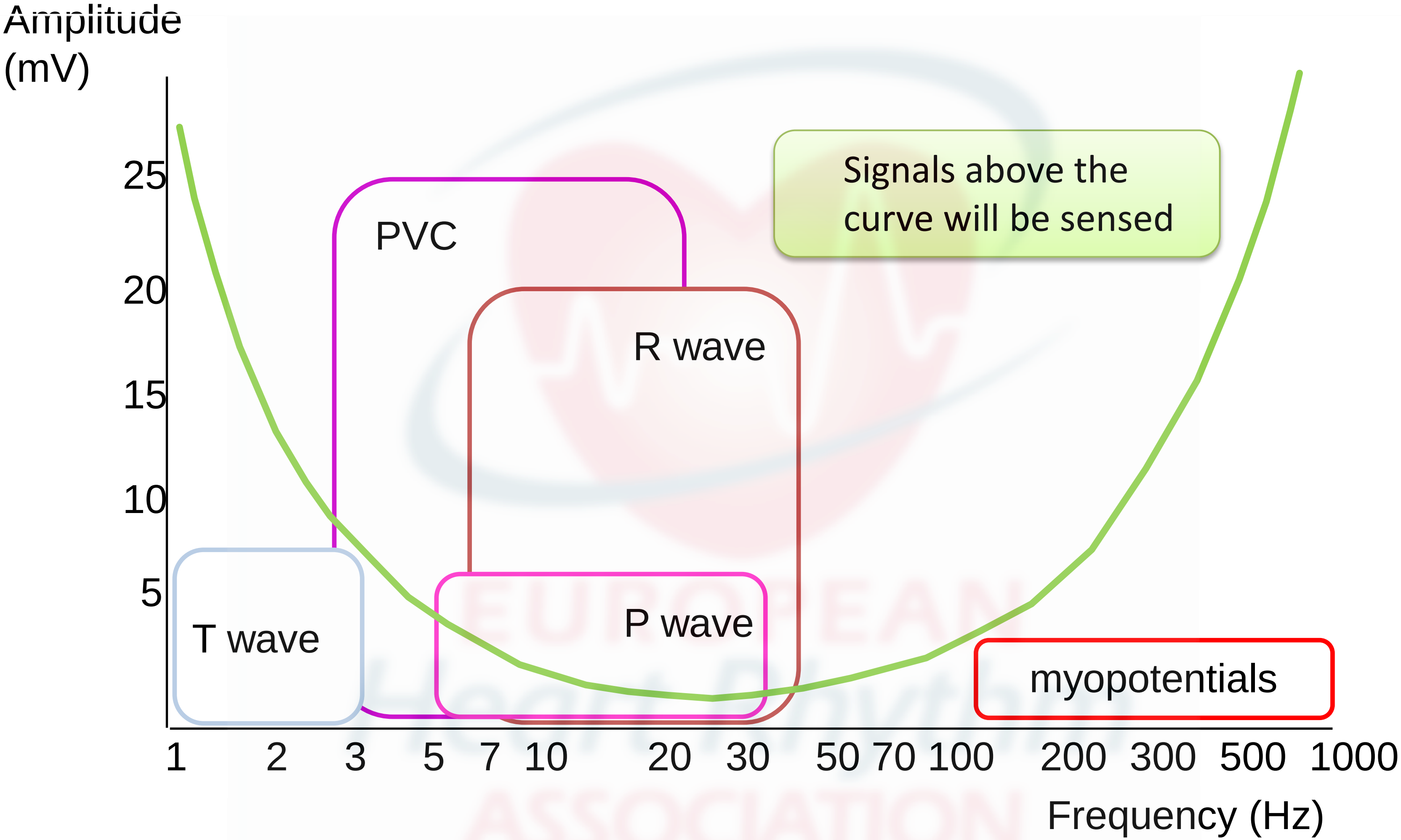
IEGM sensing



Slew rate = $\frac{(\Delta V)}{(\Delta T)}$ in volts/sec

Sensing	Atrium	Ventricle
Electrogram	>1.5-2.0 mV	>5-6 mV
Slew rate (V/sec)	>0.5	>0.5

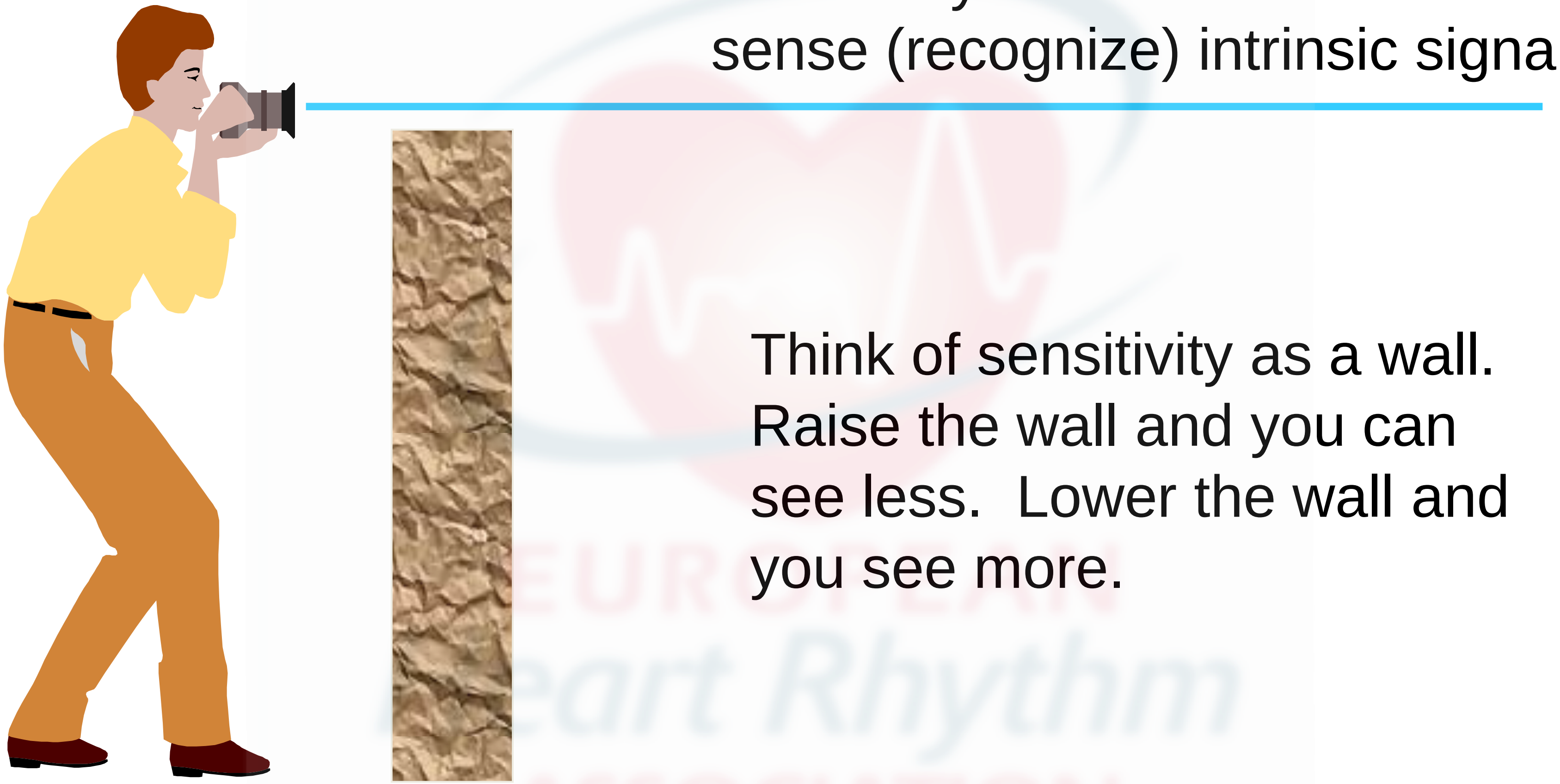
The Band Pass Filter



Filters of the atrial and the ventricular channel
may differ to optimize sensing

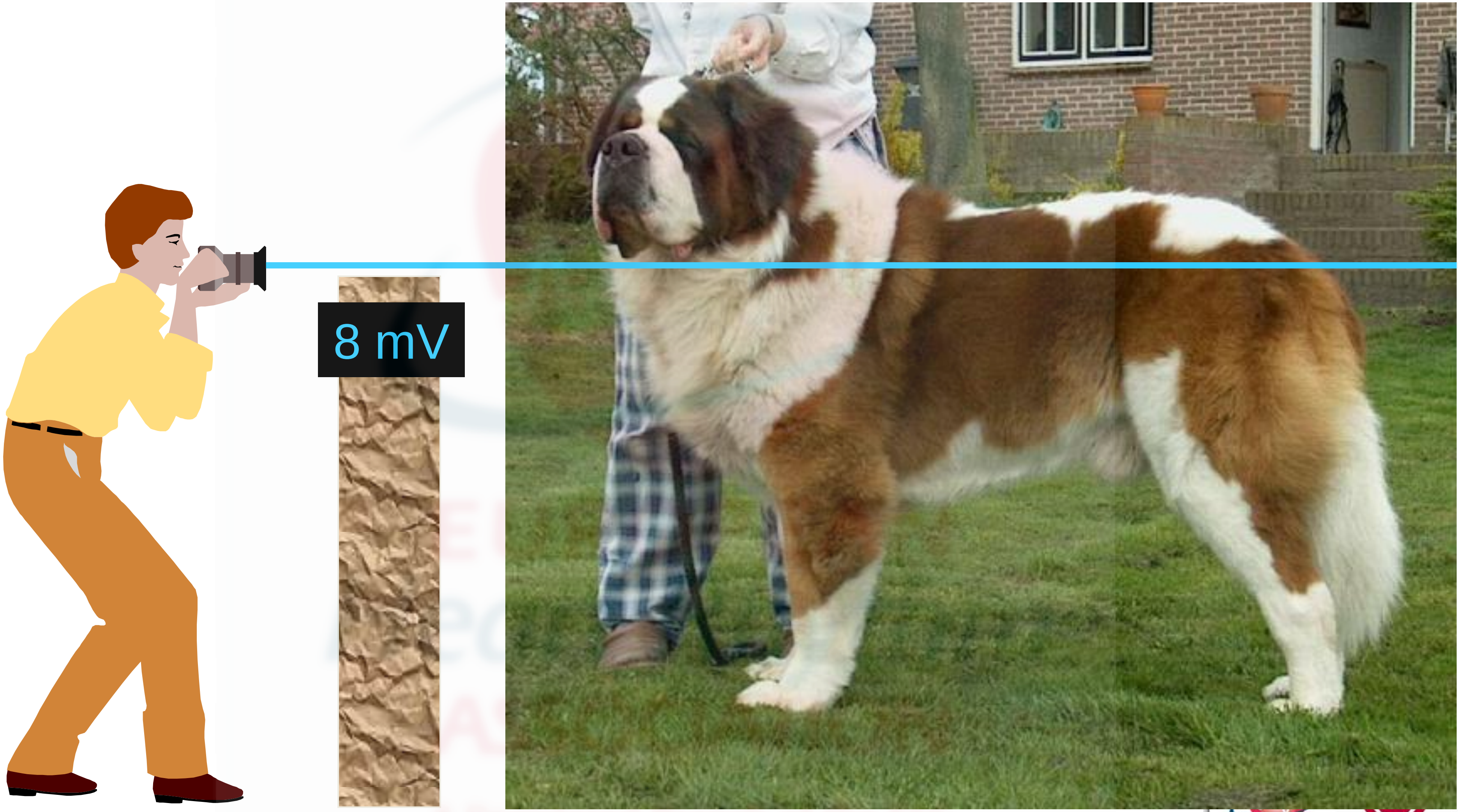
Sensitivity

The ability of a device to
sense (recognize) intrinsic signals



Think of sensitivity as a wall. Raise the wall and you can see less. Lower the wall and you see more.

Wall High : You Sense Only Large Signals

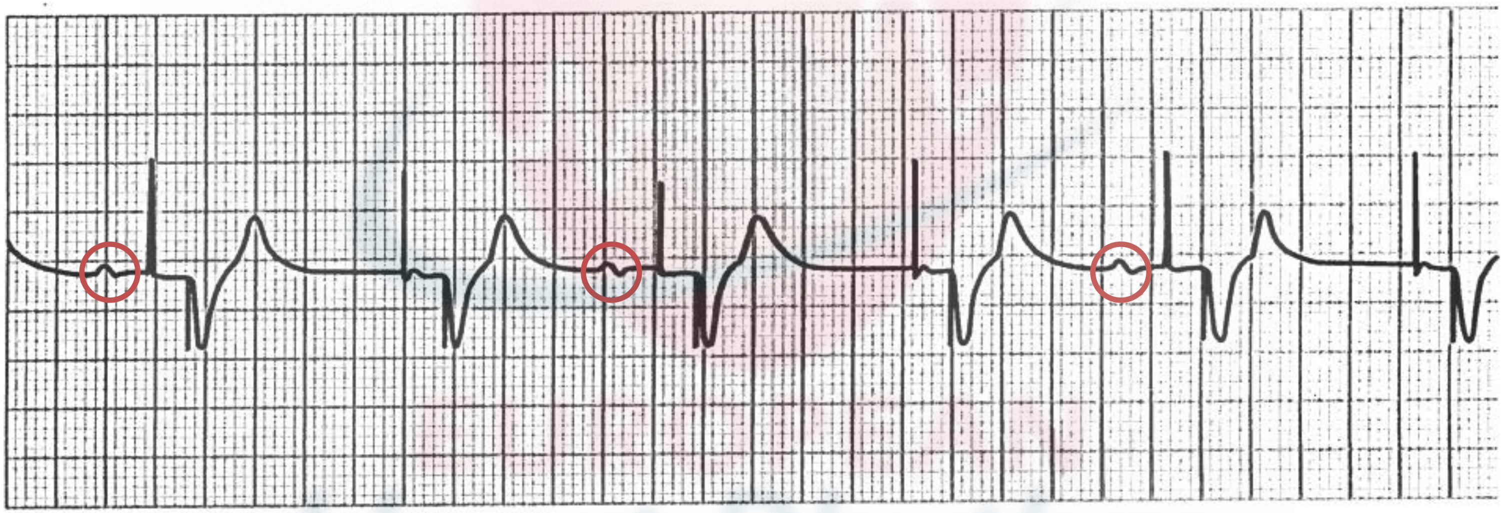


Wall lower: you also sense smaller signals

Wall too Low : You may oversense

Sensitivity - Undersensing

If the setting is too high (ie sensitivity is too low) you might miss what you need to see;

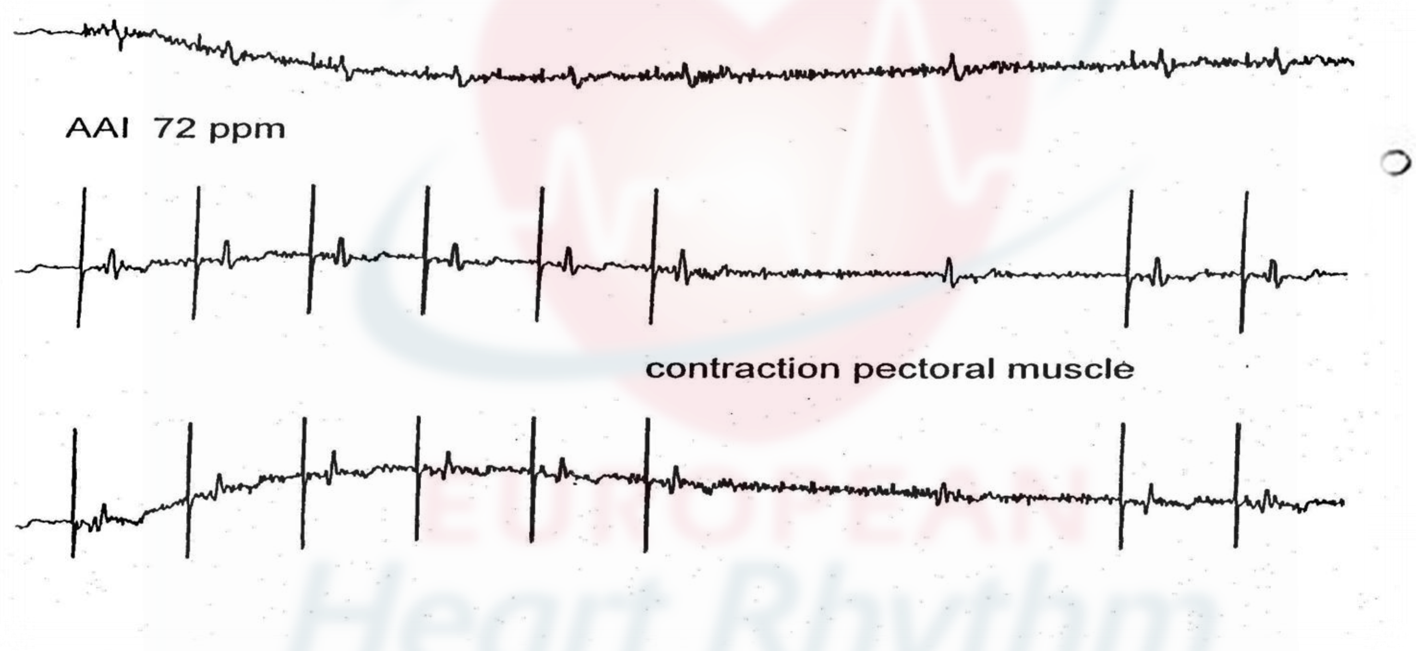


P-wave undersensing by the atrial channel

Heart Rhythm ASSOCIATION A Registered Branch of the ESC

Sensitivity - Oversensing

If the setting is too low you might get more than you asked for!



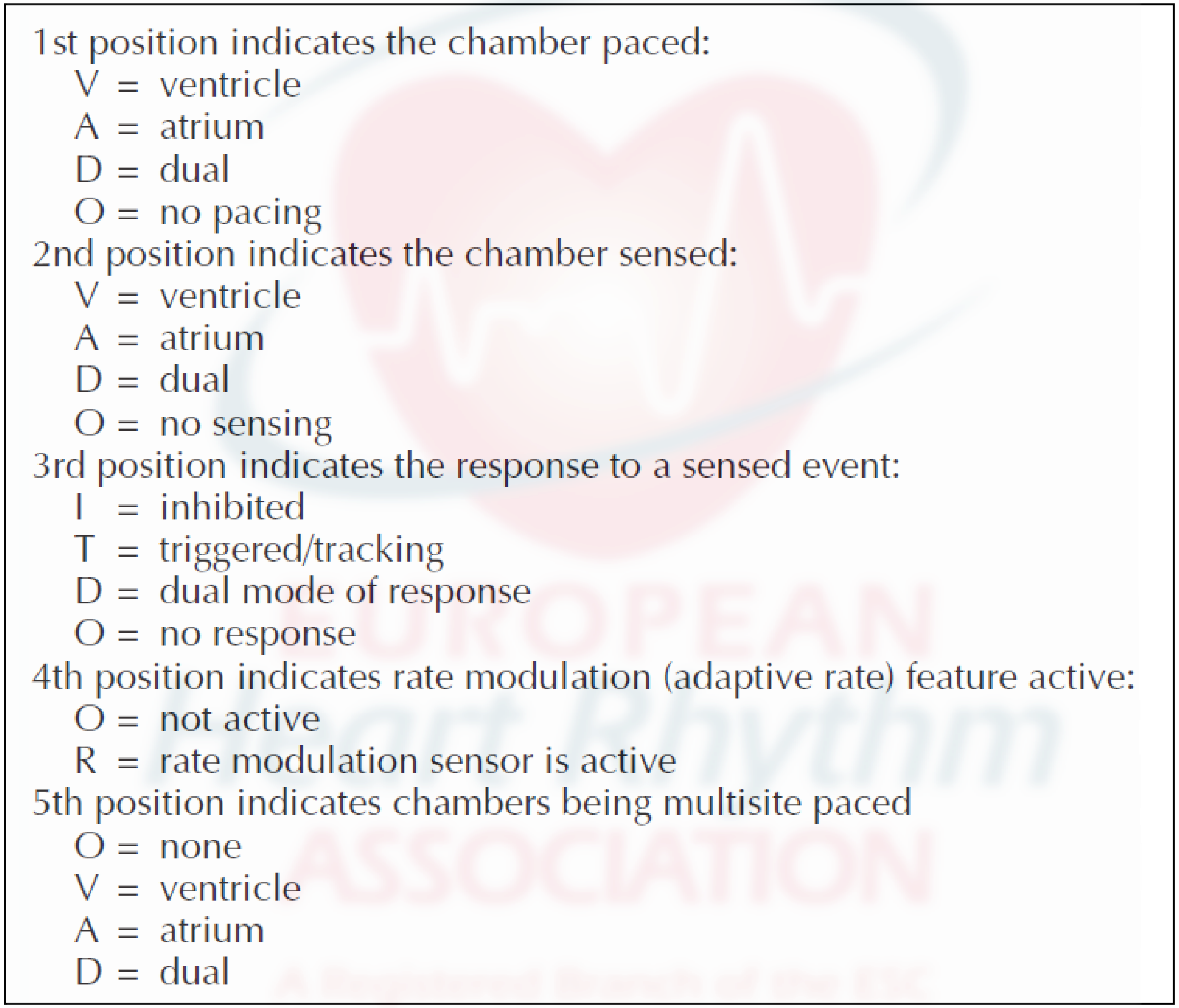
Myopotential oversensing by a unipolar atrial lead

Unipolar vs bipolar pacing/sensing

	Advantages	Disadvantages
Unipolar pacing	Large pacing artefact on ECG (easily visible) Safer in case of lead outer insulation defect No anodal capture of the myocardium	Pectoral stimulation in case of high pacing output
Unipolar sensing	-	Myopotential and EMI oversensing More far-field signals (e.g. FFRW)
Bipolar pacing	No pectoral muscle stimulation	Pacing artefact may be invisible on the ECG
Bipolar sensing	Less risk of oversensing	-

FFRW= far-field R-waves on the atrial channel

NBG code for pacemakers



1st position indicates the chamber paced:
V = ventricle
A = atrium
D = dual
O = no pacing

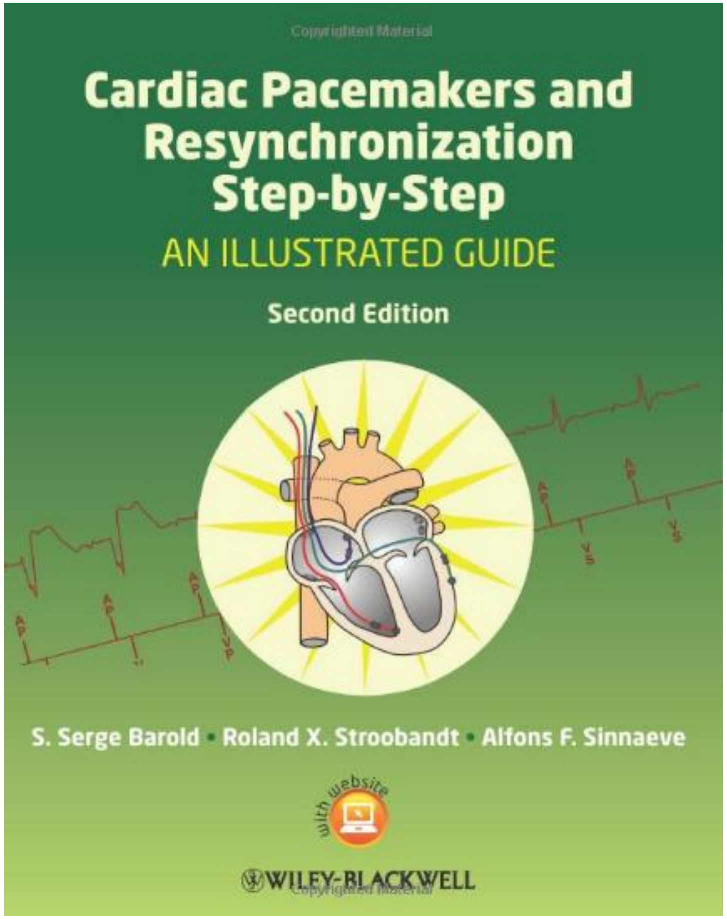
2nd position indicates the chamber sensed:
V = ventricle
A = atrium
D = dual
O = no sensing

3rd position indicates the response to a sensed event:
I = inhibited
T = triggered/tracking
D = dual mode of response
O = no response

4th position indicates rate modulation (adaptive rate) feature active:
O = not active
R = rate modulation sensor is active

5th position indicates chambers being multisite paced
O = none
V = ventricle
A = atrium
D = dual

Suggested reading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Cardiac Pacemakers and Resynchronization Step-by-Step

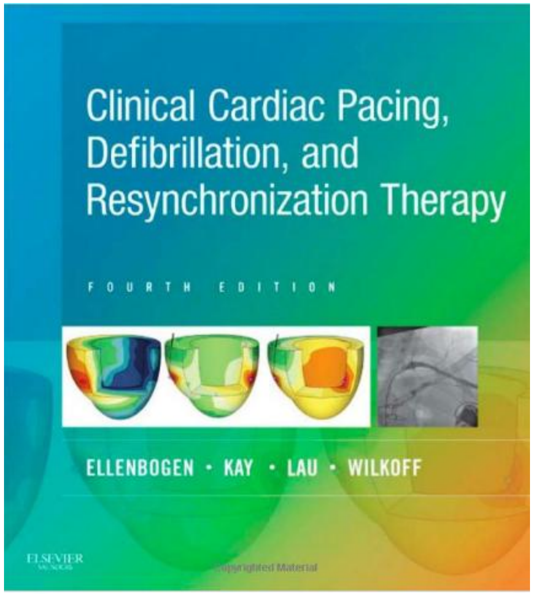
AN ILLUSTRATED GUIDE

Second Edition

S. Serge Barold · Roland X. Stroobandt · Alfons F. Sinnaeve

with website

WILEY-BLACKWELL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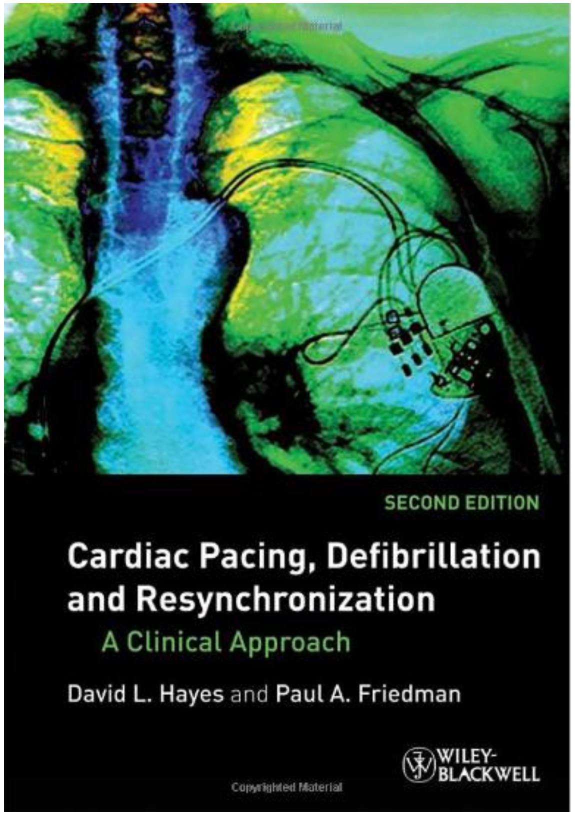
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David L. Hayes and Paul A. Friedman

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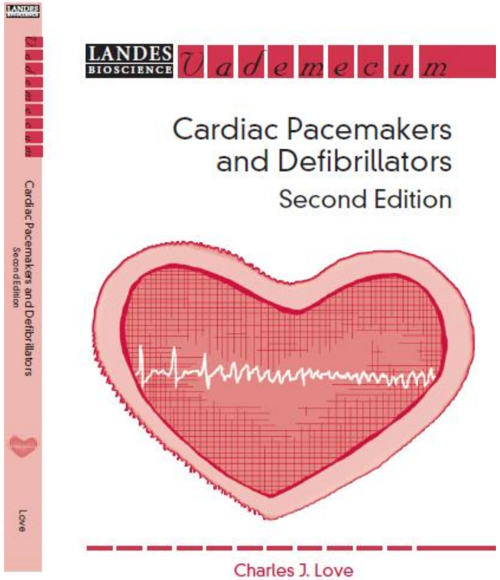
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